Captain Bayldon
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THE DEVELOPMENT OF NAVIGATIONAL INSTRUMENTS

A LECTURE

GIVEN BY MR. FRANCIS HUGHES

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A. 205

THE DEVELOPMENT OF NAVIGATIONAL INSTRUMENTS

Navigation is the science of conducting a ship or an aeroplane across the earth's surface, by using certain instruments and known information carried by those responsible for navigation on board. I propose to deal with the development of this equipment from the earliest times.

The discovery that led to the development of the first navigational instrument for use at sea was, of course, the realization of the directional properties of the magnet.

Like the inventors of the first needle, the first brick and the first wheel or like the inventor of fire on which civilization has been built, that person who first observed the curious features of the loadstone remains unknown. Not only is his name unknown, but also the age in which he lived, and even his nationality is uncertain.

One of the legends goes that the power of the loadstone, which is iron ore naturally magnetized, to attract iron, was first noticed by a shepherd conveniently named Magnes and living in Asia Minor, whose iron-tipped crook, or whose shoes soled with stub-nails clung to such a mineral. I am rather suspicious, however, as to whether primitive Asiatic shepherds wore either stub-nails or shoes.

There are many stories too about the early Chinese compasses, but it is almost certain that the Chinese never made use of the compass as an instrument to show direction. They may have used a small magnetized needle as a fortune-teller by suspending it in the centre of an ivory or hardwood dial, on which was carved or painted all the homely instances of their everyday life, such as a rainstorm, a birth or a good harvest. As they moved the dial, the needle would point to different events. One can imagine the excitement each morning as the father of the family hurried downstairs to find out what the magic needle pointed to for that day.

Of course, the difference between observing the curious properties of a mineral which will attract iron and the development of an instrument which employs this feature as a means of direction, signifies a difference in time of hundreds or even thousands of years.

The mariner's compass became known in Europe, possibly through the Arabs, between the eleventh and thirteenth centuries. Whether or not it was a European invention, its first application, doubtfully attributed to Flavio Gioja of Amalfi, coincided with the most fertile period of the Middle Ages and Italian Renaissance, other inventions at that time including printing, clocks, chimney flues, plumbing, gunpowder, spectacles, and the ship's rudder.

The first recorded voyage of a seaman bold enough to drop hugging the coast-line for several days at a time, was that of Bartolomeo Diaz who rounded the Cape in 1486 without sighting it, and there is no doubt that he used a compass.

Previous to the voyage of Diaz, we can refer to a map of 1351 known as the Laurentian Portolano, which not only shows the correct position of the Madeiras and nine of the Canaries, but also eight of the Azores, which lie 750 miles from the nearest point on the Portuguese coast, while Edrisi tells us of eight explorers who sailed west from Lisbon in the early twelfth century in a vain effort to find the limits of the western ocean.

Although the invention of the compass was the biggest stimulant that deep-sea navigation ever received, it is a curious fact that practically no attention was paid to its radical improvement from the time that Columbus employed a single needle mounted on a steel point with a paper rose up to the time of Lord Kelvin's famous patents. In the intervening centuries it received plenty of decoration and plenty of colour on the card, while the bowl or housing varied between imitations of the crowns of reigning monarchs or a painting by Titian, but it never progressed in design as scientific instruments ought to progress. Incidentally, one of the ornate decorations which still survives on the most modern marine compasses is the Fleur-de-Lys on the North point. Actually it is no Fleur-de-Lys, but probably the symbol of a lotus plant or leaf, since it was first used to decorate the East point of the compass card, then regarded as the most important, as it led in the direction that all mariners wished to go, *i.e.*, to the Islands of the Far East with all their treasures, spices, silk and gold.

In 1545, Pedro de Medina of Spain wrote the first nautical text-book, "Arte de Navegar," in which he says: "The most accurate and most valuable instrument which any ship's captain can possess, is the compass. No other instrument can show him the

course like this one can. Without it his other instruments are of little use, while with it he can go far without the others." Like Martin Cortes who published a more comprehensive volume eleven years later, Medina regards the earth as fixed, although he includes a table of sun's declination and directions for finding latitude by the Pole Star. A copy of Cortes' book was found in Novaya Zemla in 1871 among the relics left in the ice by the ill-fated Barents expedition some three centuries earlier.

One interesting piece of magnetic equipment dating from the sixteenth century was the loadstone. This stone was used as a restorative or pick-me-up for infusing magnetic strength into the compass needle from time to time, and was carried on board.

Up to 1419 when Prince Henry of Portugal founded the first nautical school at Sagres taking as its motto "Necessare est navigare" and invigorated nautical science with the possibilities of progress, all references to navigation at sea with instruments are less than vague. In those days, as Commander Gould so aptly puts it, the navigator carried all his equipment under his hat, if he wore one.

From 1419 onwards the science of navigation was strenuously prosecuted, leading to a thorough exploration of the world and therefore to the development of colonization roughly into the spheres of influence according to nationalities and natural resources which we know to-day. Henceforward the real progress in this new or revived science rested with those countries having a European-Atlantic seaboard; that is to say Portugal and Spain at first predominate, then follows the rise of British sea-power which tended to monopolize this vitally important art, while the Dutch and French made helpful contributions. And to-day the Americans taking advantage of the lie and size of their country, much in the same way as our Elizabethans dominated the seas in the sixteenth century, have developed civil air transport to a greater degree than any other country, and as a natural consequence their methods of aerial navigation are by and large, the most expert and the most progressive of all other nations.

The problem confronting the early navigators was first to decide what course they wished to steer, and secondly to check their actual position at any time when steering that course. The compass allowed them to achieve the first condition, but taking into account

the vagaries of wind, tide, current, and the speed at which they were travelling, all factors practically unknown, it was impossible to reckon accurately from a compass course or courses steered how far and on what bearing they lay from their destination.

Conceptions of latitude and longitude first took definite expression in Ptolemy's Atlas. Owing to the West-East motion of the earth, latitude, by observation of a celestial body and in conjunction with a declination table of the body observed, is relatively easy to determine. Longitude is more complex. Were the earth to rotate from South to North its computation would of course be simple, and that of latitude proportionately more difficult. The early navigators therefore first turned their attention to computing latitude from the heavenly bodies.

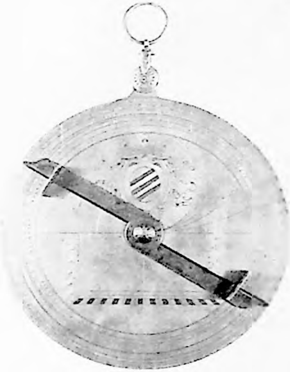
The earliest instrument either on land or sea used for this purpose was unquestionably the astrolabe. Some authorities name this the oldest scientific instrument in the world. It was first developed by the Greek and Arab astronomers and many books, including one by the poet Chaucer, have been written describing it, no two authors agreeing on its remarkable features. Either Hipparchus about 150 B.C. or Appollonius in 240 B.C. were responsible for the first model. In its simplest form it consists of a disc of wood or metal with a sighting bar, the disc being engraved with a circle of degrees. On the back is a circular map of the stars also beautifully engraved. There were countless variations in the design of this instrument, although only a mere half dozen marine astrolabes have survived.

It is a common belief that the astrolabe was and is a perfectly good instrument for taking celestial observations at sea. Actually it took three men to use it, even in the flattest of calms. There is no doubt, however, that Vasco da Gama and Columbus both possessed one, while the latter probably carried a cross-staff as well, an instrument fully described by Werner of Nuremberg in 1514. The astrolabe was even more difficult to use than the plumb-line quadrant, both of which John Davys * condemned in his "Seaman's Secrets."

Humphrey Cole, to whose inventive genius Bourne ascribes the log and line, improved the marine astrolabe in 1574, but until Davys produced his backstaff, the cross-staff held the field.

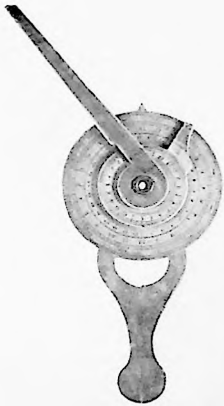
* John Davys, discoverer of Davis Straits, always signed himself with a "y."

CELESTIAL NAVIGATION



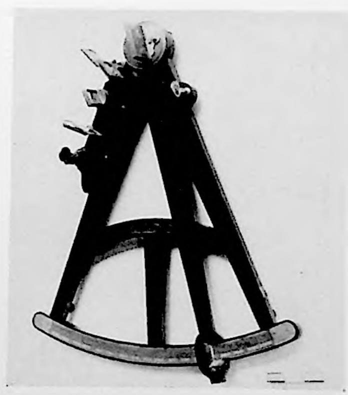
Astrolabe

Cross-Staff



Nocturnal

Davys Backstaff



Hadley Sextant

SOME OF THE EARLY CONTRIBUTORS TO THE DEVELOPMENT OF NAVIGATION

Gerard Mercator
(1512–1594)

John Flamsteed
(1646–1719)

Captain
William Bligh
(1754–1817)

John Hadley
(1682–1744)

John Harrison
(1693–1776)

Its chief fault lay in the fact that it obliged the luckless observer to look in two directions at once. Otherwise it was simplicity itself, being composed of a squared boxwood staff fitted with several sizes of " traversals " or cross-pieces sliding up and down. Its probable accuracy was to 2°. Even the modern artificial bubble horizon sextant should give accurate results to 2 minutes.

To use the backstaff, the observer turned his back to the sun, which was the only body that could be observed with this instrument. The instrument was composed of two graduated concentric arcs with a slider on each, one arc on either side of the staff. On the end of the staff was fitted a horizon sight vane at right angles. The shadow of the upper vane or slider had to be adjusted to fall on the slit in the horizon vane. If the observer could then, by looking along the lower vane and through the slit, make the horizon coincide with the shadow of the upper vane, the observation was exact, and the sum of the two readings gave him the altitude of the sun. The backstaff was gradually superseded by the sextant, although it was still in use at the end of the eighteenth century.

The essential difference between a sextant and its predecessors is the use of double reflecting mirrors. A philosopher, Robert Hooke, first proposed the idea of a single reflection-sextant, almost coincident with a similar but more scientific treatise from Sir Isaac Newton who proposed double-reflection mirrors. Neither went further than the theory, and it was not until 1730 that a practical sextant was made up in Philadelphia by Thomas Godfrey. John Hadley of London produced a similar pattern a few months later in 1731, inspired to some degree by the laments of Halley, the then astronomer-royal. There was definitely no collusion between the two inventors. The Royal Society awarded £200 to each and the instrument changed little in the next 200 years. The most important improvement was the introduction of a vernier scale first invented by Pierre Vernier in 1631.

One other interesting celestial instrument deserves notice, the nocturnal, inventor and date of which, as far as I can discover, is a dark secret.

According to Andrew Wakely, " By it may be found the Hour of the night, the Bearing of the Guards and the Declination of the North Star from the Pole ; by which may be found the Latitude." Like the astrolabe, it was circular in shape with two index arms. The

Pole Star was observed through the centre hole, the small index arm was kept stationary on the correct date engraved on the outer disc, while the larger arm was lined up on the " Guards," two stars in the Plough and Little Bear constellations. The hour of the night was read off to an accuracy of something less than 15 minutes on the inner disc. For finding latitude, the back, which was divided into a bearing circle, was consulted, together with tables known as the " Regiment of the Pole Star." All readings were read off against the forward edge of the large index arm. The instrument retained its popularity until the middle of the eighteenth century, and appears to have evolved about 1600.

Another instrument also used entirely for Pole Star observations is the somewhat mythical " magic " or " sacred " calabash said to have been used by the Hawaiians on their voyages to Tahiti and possibly from Tahiti to New Zealand roughly between the eleventh and fourteenth centuries. The Polynesians were great seamen, having an intimate knowledge of the winds and a fairly accurate conception of astronomy. They also dabbled in cartography, using strips of wood and shells. There seems to be no doubt that they accomplished voyages of more than 2,000 miles in disciplined fashion, and it may be that they had some device such as the calabash for taking star observations.

Mathematical calculations play a major part in celestial navigation, and in recent years there have been continual attempts to simplify the necessary plotting methods, tables and almanacs. When the American, Captain Sumner, in 1837 accidentally stumbled on a position line that was at right angles to the bearing of the observed object, what is sometimes called the " new navigation " received its first momentum. Andrew Wakely, in 1665, had to a certain extent anticipated him when he published " The Mariner's Compass Rectified : Containing Tables shewing the True Hour of the Day, the Sun being upon any point of the Compass," since in the seventeenth century azimuth was found at sea more accurately than the hour angle or time. In 1874, Admiral Marq St. Hilaire popularized the position line on the basis of his famous altitude-intercept formulas. Other theorists followed with a flood of tables, mostly variations on the same subject. The spherical traverse tables of the Brazilian, Captain Radler de Aquino, the haversine tables of Davis, and the remarkable position line tables of

the Japanese, Captain Ogura, first published in 1920, deserve special mention. The American Navy next caused a number of new tables to be published, culminating in 1932 with an Almanac in which Greenwich Hour Angle is separately tabulated. These efforts towards simplifying the calculations necessary for celestial navigation have been influenced by the demands of air pilots. It would be interesting to know, however, how many of the younger merchant marine officers at sea to-day are using G.H.A. and line of position methods.

Those of you here to-night who are navigators, will probably have wondered why I have not yet referred to the problem of finding longitude. Until the middle of the eighteenth century, no method had been discovered for achieving this in a practical way.

Computing longitude by dead-reckoning would be difficult enough to-day in a modern vessel that had every possible navigational appliance, but in those days when motion at sea depended on the winds, it presented intensely greater difficulties, and in hundreds of cases errors led to shipwreck and destruction. At one time it was thought that longitude might be discovered by observing the variations of the compass, and Charles II, in 1674, actually sponsored such a fantastic scheme. Even to-day, with all the data compiled since Borough first wrote his "Discourse of the Magnet and Loadstone" in 1581, to be followed by Dr. Gilbert's theory that the earth itself was a magnet, we could not compute longitude from magnetic dip to a greater accuracy than 2°.

St. Pierre next proposed observing the motions of the moon among the stars, but at that time observing instruments were inadequate, and Newton's lunar theories had not been formulated. The problem became so pressing that Philip III of Spain offered a reward of 1,000 crowns for its solution, which was followed by a prize of 10,000 florins to be given by the French. As far back as 1530, Gemma Frisius, one of the professors under whom Mercator studied, had suggested timekeepers for finding longitude, while Christian Huygens, another Dutchman and discoverer of Saturn's ring, actually designed a marine timekeeper in 1660. In 1714, Jeremy Thatcher of Yorkshire suggested a vacuum pattern and incidentally first coined the word "chronometer."

In England, Charles II decided on the recommendation of Sir

Christopher Wren and Sir Jonas Moore, to establish the Royal Observatory at Greenwich Park, which since then has rendered such signal services to the science of navigation. Flamsteed was appointed Astronomer Royal with most meagre equipment, a 7-foot iron sextant, a 3-foot wall quadrant, two telescopes and two clocks. Halley succeeded him, and pressed forward with the lunar theory first suggested by Werner of Nuremberg in 1514, the first ephemerides being computed by Tobias Mayer of Göttingen, and published at the expense of the British Government, but it was not until Nevil Maskeleyne was appointed to this office that the theory was systematized practically and accurately. It was, however, a most abstruse calculation taking anything up to four hours by Mayer's Tables. Further, an error of 1′ in the observation magnified itself into 30′, when the computation was completed. Maskeleyne's other title to nautical fame rests on the fact that he founded the British Nautical Almanac in 1766, in which lunar tables were published until 1907.

Actually William Baffin, a worthy successor to John Davys, in his efforts to discover the North-West Passage, probably holds the honour of being the first Englishman who ever took a "lunar" at sea, which he did in Hudson's Strait in 1615, together with regular daily latitude and magnetic dip observations. The "lunar" method was constantly used by James Cook on his first voyage with the assistance of Green, a former colleague of Maskeleyne, but in his subsequent voyages Cook employed "our trusty friend the Watch" as he refers to it in his diary, a reliable timekeeper having meanwhile been invented.

In 1713 several prominent British shipowners petitioned the Government to offer a reward for a method for finding longitude at sea, and the Government therefore formed a committee to consider the question, their report resulting in the establishment of a Board of Longitude in 1714. The same Act offered a graduated scale of rewards of which the highest was a glittering £20,000. This sum was to be paid to the person who devised a "generally practicable and useful" method of finding longitude at sea, which at the end of a six weeks' voyage resulted in an error of less than 30 geographical miles, that is to say, an average error of less than 3 seconds per day, a standard hitherto not even approached by pendulum clocks ashore.

It is interesting to note that Sir Isaac Newton, whom we have already mentioned in connection with the sextant, gave evidence when the original committee was formed. One of the methods enumerated by him for finding longitude was as follows :—

"One is, by a Watch to keep time exactly. But, by reason of the Motion of a ship, the Variation of Heat and Cold, Wet and Dry, and the Difference of Gravity in different latitudes, such a Watch hath not yet been made."

This disheartening statement from the most eminent scientist of his day did not however deter a young Yorkshire carpenter from seeking a solution in this direction, and thus winning the magnificent prize. John Harrison came to London in 1728, with complete drawings to construct a marine timekeeper to the desired accuracy. Receiving no assistance from the Board of Longitude, which in any case appears to have consisted of a majority of members who knew nothing whatsoever about navigation, he completed his first model six years later.

Despite scepticism, the Admiralty gave the timekeeper a trial on H.M.S. *Centurion*, where it maintained desired accuracy, and therefore its right to win the prize. This was not to take place, however, until 1773, when Harrison, an old man of eighty-three, finally completed his fifth marine timekeeper, and after King George III had intervened on his behalf. Actually half the prize was paid in 1765, and the other half in 1773, despite frantic opposition on the part of Maskeleyne and the Board itself.

I should like to say more about John Harrison and his timekeepers, partly because his contribution to marine instruments was such an important one, partly because the information available on this subject has been so fully and interestingly documented by Lieut.-Commander Rupert T. Gould, to whom I must make full acknowledgment for all the above remarks. Lieut.-Commander Gould has rivalled John Harrison in perseverance, ingenuity and enthusiasm. As many of you probably know, he spent twelve years from 1920 to 1932 restoring these most perfect examples of horological art to going order, and they are now in the newly formed National Maritime Museum at Greenwich.

Stimulated by Harrison's success, watchmakers in England and France seriously tackled the problem of producing a marine chronometer that was simple and efficient, as well as cheap in price.

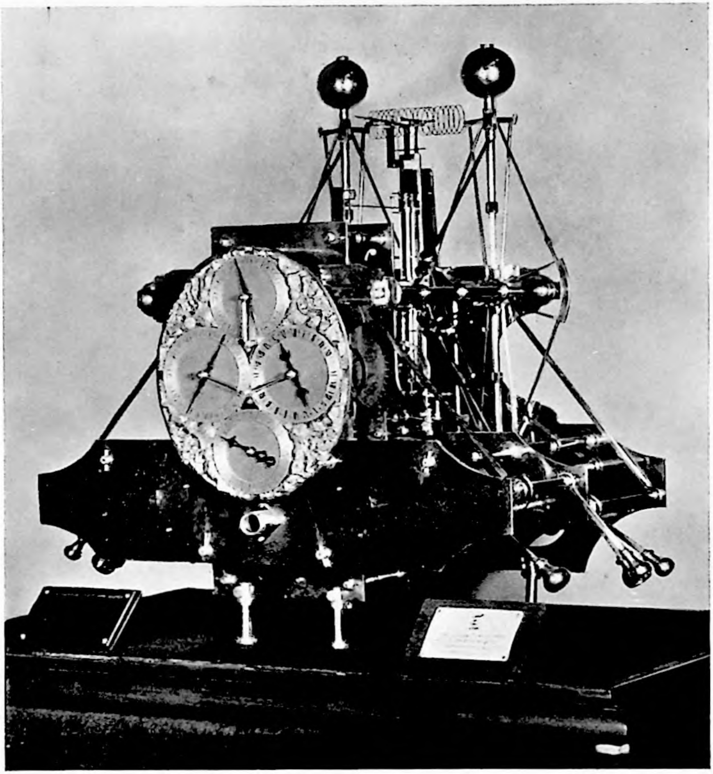
Harrison's timekeepers, despite their efficiency, were complicated and expensive. Le Roy of Paris achieved this end in 1765, but he left it to two Englishmen, John Arnold and Thomas Earnshaw, to inaugurate what might be termed the mass-production of marine chronometers, Earnshaw's model in particular being admirably simple and efficient. In fact, I think I am right in saying that Mercer of St. Albans, the largest chronometer maker to-day, still manufactures to Earnshaw's designs. I might mention too that Earnshaw once sold three of his pocket chronometers to Mr. William Hughes, one of my ancestors, and that one of these deck-watches was used by Captain Bligh of *Mutiny* fame.

Quite apart from this connection, I should like to say a few words about Bligh, as he was responsible for what is probably the greatest feat of navigation under difficulties ever performed. You will remember from the film or the book how, after being cast off by the Mutineers, he undertook his 46-day voyage in the open Long-Boat from Tofua in the Friendly Islands to Timor in the Dutch East Indies. His only instruments were a small box compass, a boxwood quadrant and a carpenter's watch which stopped soon after the voyage began. Yet his longitude error, after logging 2,200 sea-miles to the East Coast of Australia with an improvized line, was only 1° 9′ or 69 sea miles. Whatever his disciplinary methods may have been, there is no doubt that he ranks with Captain Cook as a navigator, under whom he served as a Master during Cook's third voyage.

Famous though Cook became as explorer, navigator, and the first sea captain to tackle scurvy successfully, he deserves, in my opinion, particular recognition from mariners as the first accurate hydrographer. It was due in no small part, when still a petty officer, to his accurate triangulations in and off the St. Lawrence River, that he obtained command of the *Endeavour* at the age of forty, preparatory to his first famous voyage.

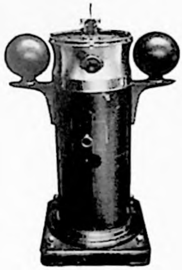
Sixteen years after Cook's death, a "Hydrographical Department," the first of its kind, was established at the Admiralty by an Order-in-Council dated August 12th, 1795. In 1825, the first catalogue of Admiralty charts comprising 736 in all was published, as against the 3,700 it comprises to-day.

Previous to this all chart-making and selling had been in private hands, dating from Ptolemy's Atlas, published in A.D. 150. As a

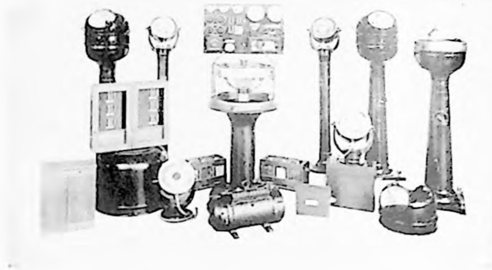


John Harrison's First Marine Timekeeper, completed in 1734

STEERING

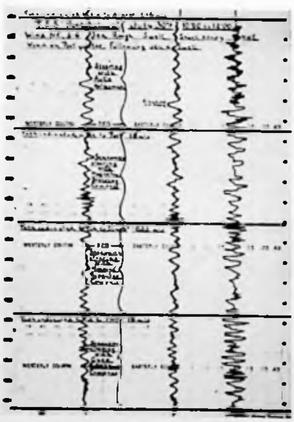


Magnetic Compass

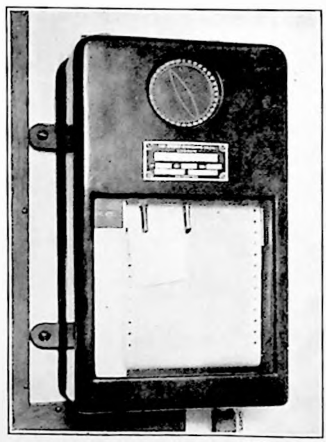


Brown Gyro Equipment

Holmes Path-finder



Four Helm Records



Sperry Course Recorder

matter of fact, Ptolemy's Atlas remained a best-seller up to the time of Columbus. Just before the famous explorer left Gomera for Watling Island, the German Behaim produced the first known globe of the universe, once and for all quashing the saucer theory of Homer. Columbus himself was of course unaware of the globe's existence.

The first map or chart seen in England was probably brought by Bartholomew Columbus in 1489, and the first map of England was made in 1520. Decimal arithmetic was invented by Simon Stevin towards the end of the sixteenth century, while Napier discovered logarithms a few years later.

The English owe a great debt to the Dutch for their early mariners' atlases, of which the first ever published was that by Wagenaar, or Waghaener, in 1583. This name was corrupted into "Waggoner," a title for sea-charts that lasted in England for a century.

Of course, the greatest of the Dutch cartographers was Mercator, who, unlike most of the navigational authorities of his day, never made a sea voyage. His projection is of little use to landsmen, and I am sorry to say he never really worked it out accurately. In 1594, the year of Mercator's death, Edward Wright, a practical navigator, discovered the correct method of dividing the meridian and supplied a table of meridional parts.

It is probable that John Davys was on the point of making the same discovery. He invariably used the globe as a chart when at sea, and deplored the pig-headedness of those mariners who persisted in using a plane-chart, by which the degrees of latitude and longitude were made of equal length, so that the error increased with the distance from the equator. In fact, Davys, who in spite of intense bad luck and furious opposition combined the duties of expert navigator, instrument designer and textbook author, like many other progressives, stands out as a prophet in the wilderness.

When reading up the lives of the early navigators and studying their equipment, it is extraordinary to remark the apathy with which new methods and new instruments were received. I am glad to think by comparison that it is easier to sell a marine superintendent an echo sounder to-day, as against the wire sounder, than it was to convince the seaman of 1594 that Davys' backstaff—then a novelty—was infinitely superior to any other observing instrument.

The second point which strikes the researcher into early records is the fact that nearly all successful theories or instruments were either invented or perfected by men who had spent at least part of, if not all, their life at sea. Such a state of affairs is impossible to-day, but I do think the contact between the practical navigator and the nautical instrument-maker might be closer, thus assisting progress in navigational technique.

Before leaving the subject of charts it would be unfair not to mention the parallel rule, which British navigators still persist in using and modifying, much to the gratification of the rule maker. Bion invented the first in 1723. Captain Fields introduced his own pattern in 1854, with degrees one side and bearings the other. The rolling parallel rule was invented by Eckhardt in 1771, while the credit for the station pointer belongs to Captain Joseph Huddart, about 1800.

The problem of calculating distance run at sea is not so essential as finding longitude or latitude, but for all practical purposes it is almost as important.

Logs and lines were part of the seamen's vocabulary in 1596, the only considerably difference being that no one at that date knew how to mark a log-line correctly. The most delightful humbug persisted among the diehards as to the advantages of marking the lines with too short divisions, *i.e.*, it would obviate the risk of running ashore.

Even when the worthy school-teacher Richard Norwood painstakingly decided to measure the actual size of a degree of latitude, or nautical mile, in 1635, " rule of thumb " navigators remained unconvinced. Norwood first ascertained the latitude of a position near the Tower of London, and two years later the latitude of a place in the centre of York, by means of a 5-foot quadrant, making the difference between the two places 2° 28′. He then proceeded to hike from London to York, measuring the distance with a chain, having first computed a special table allowing for ups and downs on the way. In certain places he was even obliged to pace the distance, but his labours were well rewarded by his resulting calculation of 2,040 yards to a nautical mile, or only 12 yards too much.

Bourne in his " Regiment of the Sea," published in 1573, gives the first full description of heaving the log and the method of timing by log glasses. This method remained popular and unaltered

for nearly 300 years, until Thomas Walker, of Birmingham, in 1865, perfected the towing log. It is a tribute to Walker that this pattern, practically unchanged to-day, is fitted on all British and foreign vessels. It is a simple instrument—in fact almost rudimentary—a rotator on a line being towed aft with a register attached, but it is remarkably accurate and still waits to be supplanted by some other method. Continual research since the Great War has been devoted to pressure logs—that is to say, calculating distance by measuring up a projected tube pressure of water at differing speeds—but so far no pattern has been generally adopted on merchant vessels.

Towards the end of the nineteenth century Sir William Thomson (later Lord Kelvin) revolutionized the marine compass. Hitherto the magnetic compass was of the crudest construction. With the introduction of iron ships it was found seriously wanting owing to the attraction of the steel plates, and despite the successful theories of compass correction advanced by Airy and Flinders.

To the many other problems unconnected with marine instruments which this great scientist tackled so successfully Lord Kelvin's dry-card compass was no exception. He produced a compass card that weighed 190 grains, as against an average of 1,600 grains in previous patterns, and fully developed the theory of compass adjusting. Simultaneously he perfected the azimuth mirror, which makes it possible to take bearings on the sun at all angles.

He researched into the question of sounding at sea. Like the log, the sounder is, so to speak, a complementary navigational instrument. It is not essential, but for practical navigational purposes indispensable. Lord Kelvin's sounder, either hand or motor driven, derives its accuracy from the use of water pressure up a coloured tube, the head of water leaving a mark at the exact depth, and thus discounting any slack in the line.

Since 1900, the development of nautical instruments may be divided as follows: firstly, the improvements to existing instruments; and secondly, the development of new instruments of a truly scientific nature and infinitely more technical than ever before.

Of the improvements, the most important is the production of a liquid compass which, under conditions of vibration and bad weather, is more steady and more responsive than the dry card. The liquid card is fitted with filaments and two short strong needles,

while such problems as expansion and contraction of the liquid and the effect of alcohol on the paint have been successfully overcome. As regards sextants, the introduction of a micrometer tangent, artificial bubble horizon and circular reflecting mirrors in a hermetically sealed mount has increased the usefulness of this instrument, which in design and fittings had remained unchanged for 200 years.

Of the new instruments, radio, the gyro compass and the echo sounder take pride of place. They have been made possible by the immense advance in other scientific fields, which is a feature of the twentieth century.

Vastly superior, however, as these new instruments are over older apparatus, yet none of them has altered the theory or practice of navigation as a science. They have only improved its operation, enhanced safety at sea, and have particularly contributed to the question of steering the shortest and quickest course, therefore saving time and fuel. So often a difference of one or two hours in the arrival time of a vessel means an extra expense of hundreds of pounds, and in the case of a large liner such as the *Queen Mary* thousands of pounds.

Of course these new instruments represent an initial expense which would have shocked any shipowner 50 years ago, and probably shocks a few to-day, but if the direction finder and the echo sounder are capable of bringing a ship into port instead of lying-to, as they do, for instance, in fog, their initial expense though relatively high, is often saved in the course of one voyage. Consequently I hope you will agree with me when I say they are being fitted not only on the large liners, but any modern steam or motor freighter should be equipped with identical apparatus.

Radio or wireless telegraphy needs no description, as its principles are well known to you all. Besides its application as a direction finder for ship-to-shore service using pre-arranged signals, it is invaluable as a means of communication.

Turning to the gyro-compass, I have heard it said of the German pattern that it ranks in mechanical construction as one of the seven wonders of the world. That statement may be somewhat exaggerated, but there is no doubt, and it is an interesting reflection, that, had the magnetic compass proved successful on naval vessels, and particularly on submarines, the gyro compass, owing

to expense and complexity, would never have been developed. Its value to merchant vessels lies in its ability to operate repeaters. It can also be linked up with an automatic steersman and will operate a course recorder. It has not, of course, supplanted magnetic compasses, and these are still fitted as before.

In connection with repeater compasses, I ought to mention that in the last decade a master magnetic compass, operating three or four repeaters, has been successfully commercialized. It is much cheaper than the gyro compass, but is not immune from deviation problems. The same inventor, an American, also produced a path indicator, which represents an entirely new aid to navigation. It is a check on a bad helmsman, as it will automatically register the departure from the set track, as against the actual course steered.

Towards the end of 1936 a unique experiment was conducted on a 10,000-ton British freighter to prove the relative merits of the different methods of steering available to-day, comprising steering with the automatic helmsman, secondly with the magnetic steering compass, thirdly with the magnetic repeater compass, and finally with the gyroscopic repeater compass. A comparison between two records, the one showing a 70-minute period of steering by the automatic pilot, the other a similar period under a helmsman using the magnetic compass repeater, proved to many persons' surprise that the difference between the two methods is negligible. Measured by the Path Finder, the distance off-track at the end of the 70-minute period was 0.030 of a mile in the case of the automatic, and in the case of the human pilot using a magnetic compass 0.04 of a mile.

Like the gyro compass and radio, the echo sounder is a complementary instrument to the practice of navigation. Sounding gives depth of water. By comparing a sounding with a chart, checking one's position, especially when landfalling, is safeguarded. In fact, fishermen proverbially trust their lead more than their compass. The echo sounder will register as many as 240 soundings per minute, and with the recording patterns it is possible to obtain a record of the sea bed over any distance, which simplifies the problem of checking one's position. It was developed in 1926, and in 10 years I estimate that more than 4,000 echo sounders, comprising the American, British and French patterns, have been

fitted, probably a record in the development of a radically new type of nautical instrument. Its value is not only confined to navigational purposes; that, of course, is its prime purpose. In the field of hydrographic surveying, which produces the all-important mariner's charts, it is recording submerged islands, wrecks, and fish, under which title I hope you will let me include an authentic case of recorded hippopotami on an African river, as well as shoals of cod off the coast of Norway. Its greatest accuracy is to 4 inches, and it can sound up to 12 miles. One of the interesting features of the magneto-striction type is the fact that it requires no piercing of the ship's hull for installation. The echo is transmitted through the steel plate.

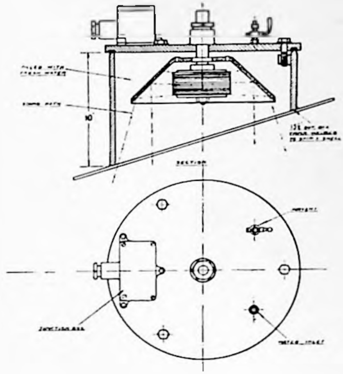
In this view of marine instrument development, it might be remarked that I have referred very largely to British ingenuity. I hope I have done so without prejudice. Since the Age of Great Discoveries, Great Britain has been linked closer than any other country with sea-power and free trade. It has followed, therefore, that the demands of her seafarers for navigational instruments stimulated invention and manufacture here to much greater purpose.

The Board of Longitude is an excellent example. It resembled the Irish Sweep in the variety and dimension of its disbursements towards any cause that benefited navigation, paying out more than £100,000 between 1714 and 1828.

Even in Germany, the home of so many fine precision and optical instruments, British marine instrument makers settled and founded the industry more than one hundred years ago. In fact, if you walk down the Stubbenhuk of Hamburg to-day, you will still find the barber's pole of the London marine optician, the "Little Midshipman" of Solomon Gills, made famous by Dickens in "Dombey and Son," as being "eternally employed outside the shop doors of nautical instrument makers in taking observations of the hackney coaches."

Turning to instruments for air navigation or "avigation" as some Americans choose to call it, British manufacturers do not hold the same predominating position. This is no aspersion on their abilities, but they have not experienced the same opportunities and rapid development in air transport as has been the good fortune of makers in the United States. The recent introduction of the new

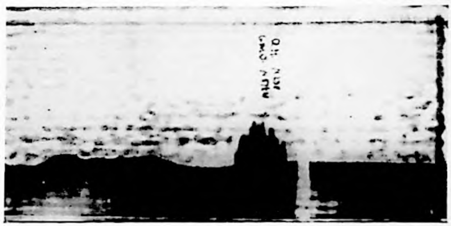
Echo-Sounder Recorder



Magneto-Striction Oscillator and Hull Tank

[*By courtesy Danish State Railways*]

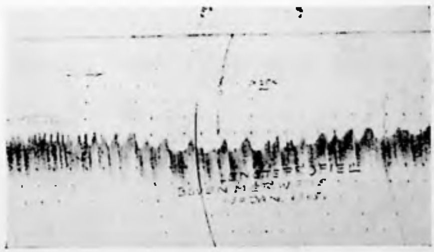
Record showing Submerged River Bed off Aarhus, Denmark



Record showing "Lusitania" lying 308 feet deep of S.W. Coast of Ireland

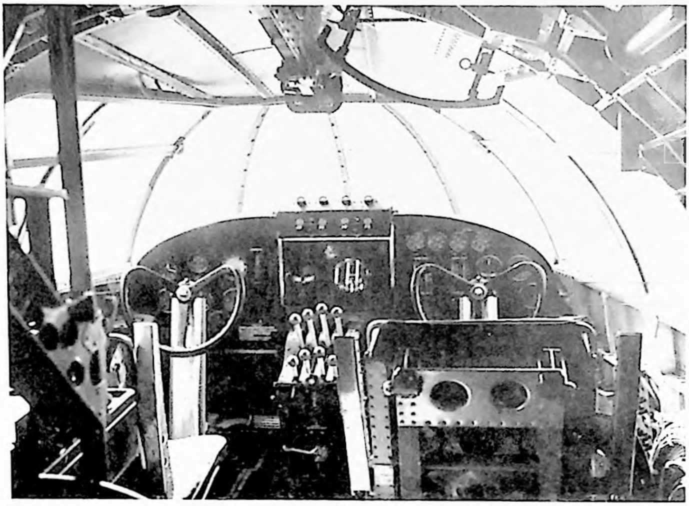
[*By courtesy Fiskeridirektoren, Norway*]

Record showing Shoals of Cod over Submarine Valley



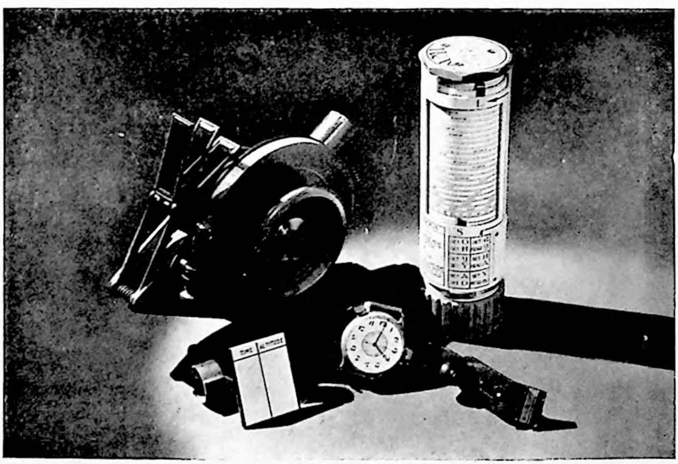
[*By courtesy Rijkswaterstaat, Holland*]

Record showing Sand Waves in the North Sea



EMPIRE FLYING BOAT DASHBOARD

APERIODIC COMPASS



AIR SEXTANT, SECOND-SETTING WATCH, SLIDE RULE

"Empire" flying boats and larger land planes has already provided a new stimulus for British manufacture.

To take the aero-compass first, I think I am right in saying that this was first tried in flight by a member of the Admiralty in 1909 piloted by Cody, taking an ordinary liquid compass resting in cotton waste in a box. For a long time the difficulties facing the employment of a magnetic compass in aircraft appeared insuperable. During the War, the Aperiodic Aero Compass was developed, which is now generally known as the P.4. Partly due to the experience of English compass makers, among whom I should like to mention my father, this compass is undoubtedly the foremost pattern to-day and is popular in America as well as in Europe.

A further development was the introduction of the Master Magnetic tele-compass fitted in the tail and therefore relatively unaffected by magnetic attraction, with a repeater in the control cabin. The gyro compass, owing to acceleration error, will not retain its accuracy for any length of time and is besides extremely heavy.

As regards the other dashboard instruments such as sensitive altimeters, artificial horizons, turn and bank indicators and automatic pilots, we have much to learn from the Americans. We cannot draw on our marine experience for such equipment. The actual dashboard arrangement is a very interesting problem, since each instrument has a differing value to the pilot while he must sit for three and four hours at a time with his eyes focussed, but not strained on those instruments that are really important.

Up to, say, 1934 the most important factor differentiating the practice of marine as opposed to air navigation, was the fact that nearly all commercial air routes were flown overland, thus receiving regular assistance from ground radio stations, light beacons, forced-landing grounds and many other aids unavailable in transmarine operation.

The equipment of air-liners for the transatlantic service is now uppermost, although it is worth noting that the Americans are already flying a transpacific route which includes a hop of greater transoceanic distance using islands as landfalls, than the great circle course from Ireland to Newfoundland.

Obviously full use will be made of radio both for communication and for navigation by D.F. bearings. It should be remembered,

however, that there are no radio stations in the Atlantic ocean, and that radio bearings lose accuracy as the range is increased. The loss in accuracy is, in fact, 1 mile in 60 for each degree the bearing is in error. Simple arithmetic will show that a bearing in error 2°, for example, will give an error in position of 1 mile in 30, or 30 miles when using a bearing from a station 900 miles distant. For homing, and for radio bearings at short range, ample accuracy is obtainable.

In the same way that radio bearings lose accuracy with distance, dead-reckoning loses accuracy as the plane proceeds along its course with a constant error to one side, and it is difficult to measure the wind draft with accuracy over the water. As a matter of fact, trans-ocean flying is accomplished above the clouds about 90 per cent. of the time—at least this has been the reports.

Fortunately, celestial navigation as used at sea, may come to be used more if with some loss of accuracy relative to marine practice. In the first place, the aircraft sextant, weighing less than 5 lb., carries its own horizon, and has it available above the clouds. This may be used through the night as well as by day. In light planes and in bumpy air the error by this method might be considerable, say, more than 10 miles. In practice, however, the planes which make such flights are large steady ones, so that sextant observations will give an accuracy to within 5 miles, and can be used with the assurance of marine sextant observations.

A unique opportunity is afforded the young airman who becomes proficient in celestial navigation. To date there has been little competition, though this will doubtless soon change. For example, the Australian, Harold Gatty, who flew round the world with Post, is not a pilot but an excellent navigator, and can command better positions than many skilled pilots.

To illustrate my point, I cannot do better than relate to you the story about Nathaniel Bowditch, the author of the "American Practical Navigator," for which I am indebted to Lieut.-Commander P. V. H. Weems.

Nathaniel Bowditch was born at Salem in 1773, the son of a shipmaster who had seen better days. After a slight amount of formal schooling he was apprenticed to a local ship chandler at the dawn of Salem's maritime expansion. He was fond of mathematics and indulged this passion by reading in the Philosophical Library of

Salem. The nucleus of this library had been captured by a Beverly privateer during the Revolution.

In 1796 he went to sea as a captain's clerk, and the following year sailed as a supercargo to Manila. On this voyage he spent every spare moment in making observations. Young Bowditch believed in a more general use of astronomical observations to check the dead-reckoning, and, in addition, he was much dissatisfied with the standard English book on navigation, by Hamilton Moore, in the tables of which he found no less than 8,000 errors. He therefore decided to publish a book of his own. In 1801, after two more voyages had given him time for practice and for an immense amount of detailed calculations, the first edition of Bowditch's "Practical Navigator" appeared. This book has been translated into a dozen languages, has passed through countless editions, and in 1930, after 129 years of service, and with a few revisions, it still remains the standard American treatise on the subject of navigation.

Bowditch next went to sea as master of the ship *Putnam*, bound from Beverly to the northwest coast of Sumatra. On the return voyage the captain made such good time that the ship had hopes of getting to Salem on Christmas Eve. December 24th, 1803, dawned with a blinding northwest snowstorm, which grew steadily worse. Bowditch was so sure of his position that he boldly approached the rocky New England coast and sailed his ship almost alongside the wharf in Salem without sighting a single landmark. He ceased to be regarded as a theorist and his position was henceforth assured. For many years "I sailed with Captain Bowditch, sir!" was a Salem man's password to an officer's berth.

Under the stimulus of simplification and ease of reading so necessary in the air, one very interesting modification of the deck watch has been introduced. An outer rotating bezel marked in seconds is fitted as well as a second-setting hand. Knowing one's minutes accurately, it is simple to set the bezel against the large sweep second hand at any given time signal, and thus to read Greenwich Mean Time on an ordinary watch with the same accuracy as on a chronometer. This watch is now being adopted by navigators at sea as well.

For the future, intensive research is being made into the possibility of developing an air echo sounder and a cathode ray compass. It is common knowledge that the barometric altimeter must be

adjusted for difference of pressure at any spot on the earth's surface over which the plane is flying and even so, owing to hysteresis, its readings are often very approximate. An air echo sounder reading to a maximum of 600 feet and to an accuracy of 10 would solve this dangerous perplexity. One of the chief difficulties against its realization is the fact that air is by no means such a satisfactory acoustic medium as water. In water, sound travels at approximately 4,800 feet per second, in air the speed is only 1,150 feet per second, and this medium is by no means so elastic. Whereas the most efficient transmission frequency in water is about 16,000 cycles per second or ultra-sonic, in air research it is being evolved towards an audible frequency of 2,000 to 3,000.

Sometimes one is inclined to feel that the problems confronting air navigation are so complicated that the aeroplane itself has tended to develop more quickly as regards speed and comfort than the navigational devices necessary to ensure complete freedom and security of operation in all weathers. The medium itself, which makes possible immensely faster transport, presents far greater problems to the navigator and instrument maker. It is fair to say, I think, that the navigational instruments are the " brains " of any plane in the air as of a ship at sea. Small in weight, inconspicuous, yet always close and visible to the pilot, they probably take up less space and less weight as against their vital importance than any other items of equipment.

You must forgive me if this lecture appears sketchy and full of acknowledgements. It is a very broad subject, and I feel that many of you here to-night are far more fitted to handle it than I am. My only excuse is that I am fond of stressing the implications of navigation and the insignificant instruments that go with it in the development of world history. It may be that the science of navigation has played no greater part in this development relatively speaking than any of the other sciences, and you may say to me what Mark Twain's stranger said about the famous jumping frog of Calaveras County, " I don't see no points about that 'ere frog what's better'n any other frog." I only hope, however, that you will not, like the stranger did, pour a handful of buckshot into my belly in order to prejudice my jumping or shall we say advertising powers on its behalf.

January 1st, 1937. FRANCIS HUGHES.